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Citation	Polar Science, 24, 100509 <a href="https://doi.org/10.1016/j.polar.2020.100509">https://doi.org/10.1016/j.polar.2020.100509</a>
Issue Date	2020-06
Doc URL	<a href="http://hdl.handle.net/2115/86117">http://hdl.handle.net/2115/86117</a>
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Type	article (author version)
File Information	manuscript received 2020-08-14.pdf



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1 **Regional comparison of seasonal changes on copepod community structure in the**  
2 **Arctic Ocean**

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**Abstract:** The Arctic Ocean is characterized as the greatly variable oceanic environment both seasonally and regionally. Such environmental variability would affect regional differences in the respective copepod community structures, though it has not been reported so far. In this study, we analyzed time-series zooplankton samples with focus on large copepods collected by sediment traps moored in three different regions of the Arctic Ocean at approximately 72-260 m water depth, and seasonality of copepod community structures were compared. Remarkable seasonality in the copepod community structure around Molloy deep in the eastern Fram Strait were due to the influence of endemic species transported by the West Spitsbergen Current. In contrast, in the southern Canada Basin (Northwind Abyssal Plain, Hanna Canyon and Barrow Canyon), the community structure of predominant large copepods showed less seasonality due to low primary production. In the MacKenzie Trough, the number of copepod swimmers were greater than those in all other regions investigated, which cooccur with much higher primary production in that area. These spatial differences in seasonality of copepod swimmer community structure were thought to be caused by various factors, not only sea ice seasonality but also differences in current patterns, endemic species and the magnitude of primary production.

18    Keywords: sediment trap; zooplankton swimmer; Arctic copepods seasonality

19 **1. Introduction**

20 In the Arctic Ocean, increase of air and sea water temperatures due to global  
21 warming induce rapid sea-ice reduction during summer (Markus et al., 2009). The  
22 concurrent drastic change of the marine environment is thought to critically affect marine  
23 ecosystems in the Arctic Ocean (Wassmann et al., 2011; Grebmeier, 2012). In the pelagic  
24 system, zooplankton organisms represent the most important prey of various higher  
25 trophic levels (Lowry et al., 2004; Wassmann et al., 2006). For instance, they are the main  
26 food source for polar cod (*Boreogadus saida*), which is an important commercial species  
27 in the Arctic Ocean (Bradstreet and Cross, 1982). Copepods can also be regarded as  
28 important indicators of currents, water mass and marine environments because of their  
29 low swimming ability and short life cycle compared to other organisms (e.g., fish)  
30 (Wassmann et al., 2006). Because of their dominance in the marine pelagic realm, it is an  
31 important topic to clarify the phenology of copepods. However, year-round ship-board  
32 observation is difficult in the deep Arctic Ocean because of the seasonal ice coverage  
33 lasting for eight months minimum. Due to this restriction, almost all studies investigating  
34 copepods in the Arctic Ocean have been carried out mainly during summertime when sea  
35 ice is very thin or melted (e.g., Springer et al., 1989). Thus, knowledge about seasonal  
36 changes within copepod community structures is still scarce.

37 Automatic sediment traps programmable to collect samples are a marine  
38 observation equipment to collect sinking particles in the water column over a certain time

39 period when mooring at fixed depths. Since automatic sediment traps can collect one-  
40 year-round or even longer, they were used in the open ocean and the Arctic Ocean where  
41 it is difficult to collect year-round samples by ship-board expeditions (Matsuno et al.,  
42 2015; Makabe et al., 2016).

43 It has been reported that zooplankton actively swim into the trap and are killed  
44 by the preservation fluid filled in the cups (Knauer et al., 1979; Ota et al., 2008).  
45 Zooplankton species composition in sediment trap samples have usually been excluded  
46 from analysis. They were picked out of the samples to avoid an overestimation of sinking  
47 particles in water column. No attention had been drawn to the picked-out swimmers in  
48 most cases. Additionally, the zooplankton collected by sediment traps is thought to be  
49 semiquantitative because they are deployed at fixed depths (Seiler and Brandt, 1997).  
50 However, in recent years that attitude has changed, seasonal changes of the zooplankton  
51 community structure have been reported after having analyzed zooplankton that swam or  
52 sunk into the collecting jars of sediment traps (Makabe et al., 2010; Kraft et al., 2012;  
53 Bauerfeind et al., 2014; Matsuno et al., 2014).

54 Studies evaluating seasonal changes on zooplankton community structures by  
55 means of sediment traps have been conducted in the Fram Strait located at the entrance  
56 of the Atlantic sector to the Arctic Ocean (Kraft et al., 2012; Bauerfeind et al., 2014). In  
57 the Fram Strait, seasonal changes in the community structures of pelagic amphipods  
58 (*Themisto libellula*, *T. abyssorum* and *T. compressa*) were reported (e.g. Kraft et al., 2012,

59 Schröter et al., 2019). The long-term seasonal changes of community structures of  
60 pteropods (*Limacina helicina* and *L. retroversa*) were revealed (Bauerfeind et al., 2014).  
61 Several studies have reported about seasonal changes of copepod community structures  
62 also for the Pacific sector of the Arctic such as for the Beaufort Sea (Makabe et al., 2010,  
63 2016) and the Canada Basin (Matsuno et al., 2014, 2015, 2016). However, those  
64 investigations were limited to only a specific region of the Arctic Ocean and thus it is still  
65 unclear how the seasonality of copepod community structures differs among various  
66 regions pan-Arctic Ocean (e.g., Fram Strait, MacKenzie Trough and Canada Basin).  
67 Periods of sea-ice coverage, amount and timing of primary production, daytime hours and  
68 the feeding environment affecting copepod community structure. Seasonal changes of  
69 these environmental factors are different between Arctic regions (Conover, 1988; Harada,  
70 2016), eventually resulting in different copepod communities in each region. Until now,  
71 there is no comparative study describing differences of seasonal changes in copepod  
72 community structures in high Arctic marine environments.

73 In this study, we compared seasonal changes of the community structures of  
74 dominant large copepods collected with time-series sediment traps moored in three  
75 different Arctic regions: Fram Strait, MacKenzie Trough and Canada Basin in order to  
76 understand the community compositions as well as to clarify what environmental factors  
77 can affect the observed differences in seasonal changes of the dominating copepod  
78 community structures.

79 **2. Material and Methods**

80 *2.1. Field sampling*

81 Time-series sediment traps were moored at seven stations in three Arctic regions  
82 (eastern Fram Strait, Canada Basin and MacKenzie Trough) collecting samples  
83 throughout several seasons between 2010 and 2016 (Fig. 1, Table 1).

84 *Fram Strait:* Two time-series sediment traps (K/MT 234, open mouth area 0.5  
85 m<sup>2</sup>, Kiel) were moored at St. N-4 (79.7°N, 4.5°E, 2670 m bottom depth) and St. HG-IV  
86 (79.0°N, 4.3°E, 2600 m bottom depth) in eastern Fram Strait from 15 July 2010 to 15  
87 June 2014 and from 10 July 2010 to 15 June 2014, respectively (Fig. 1, Table 1). Range  
88 of the sediment trap depths were 190–205 m at St. N-4 and 200–205 m at St. HG-IV,  
89 respectively. The cups of sediment traps were automatically rotated and replaced at 5–59  
90 days (St. N-4) and 7–59 days (St. HG-IV), respectively. Twenty collection cups were used  
91 to collect samples per year. However, 13–19 samples per year in N-4 and 17–20 samples  
92 per year in HG-IV were used for analysis because of sediment trap funnel clogging during  
93 few summer sampling intervals.

94 *Canada Basin:* In total three trap arrays were moored. A time-series sediment  
95 trap (SMD26S-6000, open mouth area 0.5 m<sup>2</sup>, Nichiyu Giken Kogyo, Co. Ltd.) was  
96 moored at St. NAPt (75.0°N, 162.0°W, 1910 m bottom depth) of Northwind Abyssal Plain  
97 of Canada Basin from 4 October 2010 to 10 September 2014 (Fig. 1 and Table 1). Range

98 of the sediment trap depths were 186–260 m. The cups of sediment traps were replaced  
99 at 10–15 days, and twenty-six collection cups were used per year. Another time-series  
100 sediment trap (SMD26S-6000, open mouth area 0.5 m<sup>2</sup>, Nichiyu Giken Kogyo, Co. Ltd.)  
101 was moored at a different location within the Canada Basin during 1-year at St. NHC  
102 (73.3°N, 160.8°W, 426 m bottom depth) of North of Hanna Canyon in Canada Basin from  
103 28 September 2015 to 10 September 2016 (Fig. 1, Table 1). The sediment trap depth was  
104 deployed at 170 m. Collection interval were 7–14 days and twenty-six collection cups  
105 were used. But twenty-four samples were used for analysis because of sediment trap  
106 funnel clogging during few summer sampling intervals. A third time-series sediment trap  
107 (SMD26S-6000, open mouth area 0.5 m<sup>2</sup>, Nichiyu Giken Kogyo, Co. Ltd.) was moored  
108 at St. NBC (72.5°N, 155.4°W, 2000 m bottom depth) of North of Barrow Canyon in  
109 Canada Basin from 21 September 2015 to 9 September 2016 (Fig. 1, Table 1). The  
110 deployed trap depth was approximately 250 m. Collection interval were 12–14 days and  
111 twenty-six collection cups were used. Again, only twenty samples were used for analysis  
112 because of sediment trap funnel clogging during few summer sampling intervals.

113 *MacKenzie Trough:* In total two moorings were deployed over a time interval of  
114 one year only. At St. MG (71.0°N, 135.3°W, 700 m bottom depth) of the MacKenzie  
115 Trough off the coast in Beaufort Sea, a time-series sediment trap (PPS. 6/2, open mouth  
116 area 0.5 m<sup>2</sup>, Technicap) was moored at 125 m depth from 20 September 2011 to 2  
117 September 2012 (Fig. 1, Table 1). Collection interval days were 8–16 days and twenty-

118 four collection cups were used. In addition, at St. MA (70.5°N, 136.0°W, 680 m bottom  
119 depth) of the MacKenzie Trough, two time-series sediment traps (PPS. 3/3, open mouth  
120 area 0.125 m<sup>2</sup>, Technicap) were moored at 72 and 172 m depths from 14 September 2011  
121 to 2 September 2012 (Fig. 1, Table 1). Collection interval days were 8–17 days and  
122 twenty-four collection cups were used each depth.

123           Fixation of collected material was different: The sample cups of the sediment  
124 traps at St. N-4 and St. HG-IV were filled with mercuric chloride (0.14% final solution)  
125 and 5% buffered formalin seawater was used all the other stations to preserving sinking  
126 particle and zooplankton swimmer.

## 127 *2.2. Environmental data from satellite*

128           The weekly average of sea-ice coverage near each station during the mooring  
129 periods were calculated at 25-km resolution from the sea-ice concentration dataset  
130 (National Snow and Ice Data Center). MODIS/Aqua Level 3 binned chlorophyll *a* data  
131 was downloaded from the Distributed Active Archive Center (DAAC) of the Goddard  
132 Space Flight Center (GSFC) of NASA and a running mean of 9 days were calculated by  
133 9-km resolution. Daytime hours at each station were calculated according to Brock (1981).

## 134 *2.3. Sample analysis*

135           The zooplankton samples from eastern Fram Strait (St. N-4 and HG-IV) were

136 gently filtered with a 0.5-mm mesh net, and the organisms retained on the mesh net (>  
137 0.5 mm size) were treated as zooplankton swimmers. Large copepods (prosome width  
138 >1.41 mm) were identified to species level according to Brodsky (1967) and counted  
139 under a stereo microscope. Because species identification using morphological features  
140 between three *Calanus* developmental stages (*Calanus hyperboreus*, *Calanus glacialis*  
141 and *Calanus finmarchicus*) was difficult, we identified them using prosome length of each  
142 copepodite stage (Hirche et al., 1994; Kosobokova and Hirche, 2016; Table 2). In addition,  
143 species identification for the younger than copepodite stage 5 of *Paraeuchaeta glacialis*  
144 and *Paraeuchaeta norvegica* was not possible (Auel, 1999), we treated these species as  
145 *Paraeuchaeta* spp.

146 The samples from the other station (St. NAPt, NHC, NBC, MG and MA) were  
147 gently filtered through a 1-mm mesh net, and the organisms retained on the mesh net (>1  
148 mm size) were treated as zooplankton swimmers. Large copepods fraction of the  
149 zooplankton swimmers was identified at species level and counted according to Brodsky  
150 (1967).

151 The flux ( $F$ , individuals  $\text{m}^{-2} \text{day}^{-1}$ ) of zooplankton swimmers was calculated  
152 using the following equation:

$$153 \quad F = N \times \frac{1}{O} \times \frac{1}{d}$$

154 where  $N$  is the number of individuals,  $O$  is the mouth area ( $\text{m}^2$ ) of the sediment trap and

155  $d$  is the collection interval (days).

#### 156 2.4. Data analysis

157 Flux data (ind. m<sup>-2</sup> day<sup>-1</sup>) of large copepods (prosome width >1.41 mm) for each  
158 station were forth root transformed. Similarities between samples were examined using a  
159 Bray-Curtis similarity index and dendrogram created using Unweighted Pair Group  
160 Methods using Arithmetic mean (UPGMA) were punctuated arbitrary similarity to group  
161 samples (Field et al., 1982). According to these groups, average flux (ind. m<sup>-2</sup> day<sup>-1</sup>) and  
162 contribution percentage (%) of the dominant large copepods of each group were  
163 calculated by similarity percentages (SIMPER). Besides, nonmetric multidimensional  
164 scaling analysis (NMDS) was carried out using same similarity to confirm relationship  
165 between groups and environmental factor (sea ice concentration, surface chlorophyll  $a$   
166 and daytime) . All these analyses were carried out using PRIMER 7 software (PRIMER-  
167 E Ltd.).

### 168 3. Results

#### 169 3.1. Hydrography

170 In the Fram Strait, polar night occurred from mid-October to mid-February, and  
171 midnight sun was observed from mid-April to mid-August. The sea ice concentration  
172 (SIC) around St. N-4 of eastern Fram Strait showed no clear seasonal changes related

173 with seasonality of sun and low coverage (4 years average 8.79%) throughout the year  
174 (Fig. 2a). SIC increased during October and March of 1<sup>st</sup>, 3<sup>rd</sup> and 4<sup>th</sup> year, but during  
175 September and March of 2<sup>nd</sup> year was very low. Surface chlorophyll *a* (Chl. *a*)  
176 concentration ranged between 0.05–3.87 mg m<sup>-3</sup> and showed peaks from May to June.  
177 The SIC around St. HG-IV of eastern Fram Strait was even lower than St. N4 and reached  
178 about 40% in spring (Fig. 2b). Also, SIC was increasing in October and June of 3<sup>rd</sup> year.  
179 Surface Chl. *a* concentration ranged between 0.02 and 16.7 mg m<sup>-3</sup>, which was 4 times  
180 higher than these of St. N-4, but the timing of the peaks was similar at the both stations.

181         The SIC around St. NAPt of Canada Basin showed clear seasonal changes (4  
182 years average 76.2%), and sea ice completely melted from August to October and rapidly  
183 increased from October to November (Fig. 2c). Surface Chl. *a* concentration increased  
184 when sea ice melting, and the values were much lower than at all the other stations  
185 (0.02–0.35 mg m<sup>-3</sup>). Midnight sun occurred from late April to early August, and polar  
186 night was observed from late October to early February. Sea ice concentration at St. NHC  
187 (1-year average 72.6%) was increasing rapidly from mid-October and melted mid-June,  
188 and completely sea-ice melting period was observed in August (Fig. 2d). Only 7 valid  
189 surface Chl. *a* was detected during open ocean period because of a lot of clouds. Polar  
190 night was observed from early November to early February, and midnight sun occurred  
191 from early May to early August. Rapid freezing was observed from mid-October to mid-  
192 November, and gradual melting occurred from mid-May at St. NBC (1-year average

193 68.4%) (Fig. 2e). Surface Chl. *a* could be detected only 1 time in September because of a  
194 lot of clouds. Polar night and midnight sun period were almost same as St. NHC.

195           The SIC of St. MG and St. MA of the MacKenzie Trough increased rapidly from  
196 late October to mid-November and it was more than 90% from mid-September to mid-  
197 May, and sea ice rapidly decreased from mid-May to mid-June (Fig. 2f, g). 1-year average  
198 of SIC is 59.3% at St. MG and 58.3 % at St. MA, respectively. Surface Chl. *a*  
199 concentration was increased during open water period (from July to August), and the  
200 values were higher than at all other stations (0.03–38.9 mg m<sup>-3</sup>). Polar night and midnight  
201 sun occurred from mid-November to mid-January and early May to late July, respectively.

### 202 3.2. Community structure

203           In the eastern Fram Strait, *C. finmarchicus*, *C. glacialis*, *C. hyperboreus*,  
204 *Metridia longa*, *Paraeuchaeta* spp. and *Heterorhabdus norvegicus* dominated. Flux of  
205 these dominant large copepods changed from 1.25 to 164 ind. m<sup>-2</sup> day<sup>-1</sup> (mean ± sd: 25.9  
206 ± 28.3 ind. m<sup>-2</sup> day<sup>-1</sup>) at St. N-4 and 0.93 to 128 ind. m<sup>-2</sup> day<sup>-1</sup> (36.4 ± 35.0 ind. m<sup>-2</sup> day<sup>-1</sup>)  
207 at St. HG-IV (Fig. 3a, b). The flux of the large copepods in St. N-4 showed two peaks  
208 every year, first peak was from March to May and second peak was from August to  
209 October. The flux of the second peak was higher than that of the first peak. The flux at St.  
210 HG-IV showed two peaks every year, first peak was from March to May and second peak  
211 was from August to October. The flux of the first peak and the second peak were almost

212 equal, but the species composition changed: the composition of *C. finmarchicus* was high  
213 in the first peak despite 1<sup>st</sup> year, while *M. longa* and *Paraeuchaeta* spp. were dominant in  
214 the second peak.

215 In the Canada Basin, *C. glacialis*, *C. hyperboreus*, *M. longa*, *Paraeuchaeta* spp.,  
216 *H. norvegicus* and *Gaetanus tenuispinus* were observed at St. NAPt (Fig. 3c). The flux of  
217 these large copepods changed from 1.29 to 36.9 ind. m<sup>-2</sup> day<sup>-1</sup> ( $10.8 \pm 5.93$  ind. m<sup>-2</sup> day<sup>-1</sup>).  
218 Seasonal fluctuation of the flux throughout year was smaller than those in the Fram  
219 Strait, but the flux showed two small peaks in March-August and September-October  
220 with increasing share of the composition by *C. hyperboreus*. At St. NHC, *C. glacialis*, *C.*  
221 *hyperboreus*, *M. longa*, *Paraeuchaeta* spp., *H. norvegicus* and *Chiridius obtusifrons* were  
222 abundant and the flux of these large copepods ranged between 2.15 and 42.7 ind. m<sup>-2</sup> day<sup>-1</sup>  
223 ( $9.05 \pm 8.72$  ind. m<sup>-2</sup> day<sup>-1</sup>) (Fig. 3d). Two peaks of the flux were observed from April  
224 to June and October with dominance of *Paraeuchaeta* spp. and *M. longa*. At St. NBC, *C.*  
225 *hyperboreus*, *M. longa*, *Paraeuchaeta* spp., *H. norvegicus*, *G. tenuispinus* and *Aetideopsis*  
226 spp. occurred (Fig. 3e). The flux of these large copepods changed from 0.71 to 21.4 ind.  
227 m<sup>-2</sup> day<sup>-1</sup> ( $8.23 \pm 4.86$  ind. m<sup>-2</sup> day<sup>-1</sup>). The peaks on the flux were observed in March-May  
228 and September-November, and composition of *C. hyperboreus* was high at the spring  
229 peak. In addition, share of *H. norvegicus* on the flux was higher than that of at St. NHC.

230 In the MacKenzie Trough, *C. glacialis*, *C. hyperboreus*, *M. longa*, *Paraeuchaeta*  
231 spp, *G. tenuispinus* and *C. obtusifrons* dominated at St. MG (shallow) (Fig. 3f). The flux

232 of these copepods ranged from 0.30 to 268 ind. m<sup>-2</sup> day<sup>-1</sup> (45.8 ± 63.1 ind. m<sup>-2</sup> day<sup>-1</sup>) and  
233 showed a peak in September-October with dominance of *Paraeuchaeta* spp. and *M. longa*.  
234 At St. MA (shallow and deep traps), *C. glacialis*, *C. hyperboreus*, *M. longa*, *Paraeuchaeta*  
235 spp., *H. norvegicus* and *G. tenuispinus* were abundant (Fig. 3g, h). The flux of the  
236 copepods at St. MA (shallow) changed from 38.7 to 1440 ind. m<sup>-2</sup> day<sup>-1</sup> (295 ± 290 ind.  
237 m<sup>-2</sup> day<sup>-1</sup>) and maximum flux was the highest comparing to all other stations. The flux  
238 showed a peak in September-October and low in November-January and no clear seasonal  
239 change from February to August. With the seasonal change of the flux, dominant species  
240 changed: *Paraeuchaeta* spp. dominated in the peak of September-October, *C. glacialis*  
241 occurred in January-April and *M. longa* were abundant from May to July. The flux of the  
242 copepods at St. MA (deep) ranged from 3.23 to 126 ind. m<sup>-2</sup> day<sup>-1</sup> (25.6 ± 23.7 ind. m<sup>-2</sup>  
243 day<sup>-1</sup>). Similarity was observed in seasonal change on flux between shallow and deep  
244 traps at St. MA, but *C. hyperboreus* and *H. norvegicus* were higher in deep trap than these  
245 of shallow.

246 To clarify seasonal change and comparison between stations of copepod  
247 community structure, copepod communities were divided into 10 groups (A-J) with 74%  
248 similarity using cluster analysis based on flux (Fig. 4a). Then, we classified groups  
249 including less than 2 samples as not-available group (NA) and did not use it for later  
250 analysis. Average fluxes in the order of group A to J were 250, 22.5, 10.9, 5.88, 7.28, 9.96,  
251 19.3, 39.8, 61.1 and 39.3 ind. m<sup>-2</sup> day<sup>-1</sup> (Fig. 4b). The average flux of group A was the

252 highest, and group D had the lowest in all groups. As results of SIMPER (Table 3),  
253 *Paraeuchaeta* spp. (contribution percentage: 58.5%), *M. longa* (19.8%) and *C. glacialis*  
254 (13.2%) dominated in group A, and the share of *C. glacialis* was higher than those of the  
255 other groups. *M. longa* (52.7%), *H. norvegicus* (26.8%) and *Pseudocalanus* spp. (12.0%)  
256 dominated in group B, and *Pseudocalanus* spp. was only found in the group B as  
257 dominant species. In group C, *M. longa* (30.4%), *H. norvegicus* (26.8%) and  
258 *Paraeuchaeta* spp. (11.9%) were dominant. Similar to group C, *M. longa* (40.8%),  
259 *Paraeuchaeta* spp. (27.5%) and *H. norvegicus* (18.8%) dominated in group D.  
260 Dominant species of group E were *M. longa* (60.1%), *Paraeuchaeta* spp. (17.0%) and *H.*  
261 *norvegicus* (11.4%), and *M. longa* occupied more than half on total of flux. *Paraeuchaeta*  
262 spp. (70.1%) dominated, and *M. longa* (24.7%) and *C. hyperboreus* (3.4%) predominated  
263 in group F. *M. longa* (50.7%), *Paraeuchaeta* spp. (28.1%) and *C. hyperboreus* (9.6%)  
264 occurred in group G. In the group H, dominant species were *Paraeuchaeta* spp. (52.2%),  
265 *C. finmarchicus* (33.7%), *M. longa* (6.1%) and many *C. finmarchicus* were observed  
266 comparing to the other groups. *Paraeuchaeta* spp. (55.5%), *M. longa* (29.9%) and *C.*  
267 *glacialis* (5.0%) occurred in group I. *Paraeuchaeta* spp. (43.5%), *M. longa* (34.3%) and  
268 *C. hyperboreus* (16.0%) dominated in group J. To analyze relationship between copepods  
269 assemblage and environmental factor, NMDS was carried out. But this result wasn't used  
270 according to Clarke and Warwick (2001) because stress value was 0.22.

271           Seasonal changes on copepod groups identified by cluster analysis on flux at

272 each station were shown in Fig. 5. Seasonal changes were clearly observed in the eastern  
273 Fram Strait (St. N-4 and St. HG-IV). Groups E, F and H occurred in winter (January-  
274 March), groups E, F and J were shown in spring (April-June), group I was observed in  
275 summer (July-September) and group I and E occurred in autumn (October-December).  
276 Groups E, H, I and J were observed only in eastern Fram Strait. In the St. NAPt, copepods  
277 community showed no clear seasonal change and group C was mainly dominant. At St.  
278 NHC, occurrences of the groups C, D, F and G changed within short periods (monthly or  
279 every two weeks). Seasonal change of community structure in NBC was similar to that  
280 of St. NAPt. In the MacKenzie Trough, groups A, B, C, E, F and G were observed at St.  
281 MG and the copepods community exchanged in the short periods (monthly or every two  
282 weeks). At St. MA (shallow), group B occurred only in winter, and the other seasons were  
283 occupied by group A. In the St. MA (deep), group A and B occurred from autumn, but the  
284 occurrences of groups C, D, F and G were exchanged complexly from winter to summer.  
285 The groups A and B were observed only in the stations of the MacKenzie Trough (St. MA  
286 and St. MG).

## 287 **4. Discussion**

### 288 *4.1. Zooplankton sampling by sediment trap*

289 For quantitative evaluation of abundance, biomass and distribution of  
290 zooplankton species, plankton net sampling is the common method (e.g., Darnis and

291 Fortier, 2014), although it is known that some large zooplankton may avoid the net. While  
292 zooplankton collected by net reflect most of the zooplankton in the towed water layers,  
293 sediment trap sampling of zooplankton is believed to reflect only the organisms occurring  
294 around the sediment trap depth layer because the sediment trap depth is fixed at a certain  
295 depth (Seiler and Brandt, 1997). This is regarded as a disadvantage and it is argued that  
296 sediment trap sampling therefore does not reflect the zooplankton community as a whole.  
297 In addition, zooplankton seems to be attracted by the trap's abundances and by the  
298 respective preservatives so that collecting zooplankton with traps can only be regarded as  
299 a semi-quantitative method (see also Lee et al., 1992). However, since high-frequency  
300 investigations using research vessels are very difficult and expensive in the Arctic Ocean  
301 because of sea-ice coverage, very low temperatures and the Polar Night samples collected  
302 by sediment trap is an effective method to clarify seasonal changes on zooplankton  
303 communities in certain depth and allow to explain ecological phenology like life cycles  
304 of copepods in the Arctic Ocean (Tokuhiro et al., 2019). The few studies of zooplankton  
305 collected by means of sediment traps in the Arctic Ocean, reveal reproducible seasonal  
306 changes on community structure of, for instance pelagic amphipods, like *Themisto* spp.  
307 and pteropods *Limacina* spp. in the eastern Fram Strait (Kraft et al., 2012; Bauerfeind et  
308 al., 2014) and seasonal changes on copepod community structure in the Chukchi Sea and  
309 the Beaufort Sea (Makabe et al., 2010; Matsuno et al., 2014, 2015, 2016; Tokuhiro et al.,  
310 2019). Thus, despite the disadvantages, the sampling of zooplankton swimmers with

311 sediment traps have been gradually recognized as an approach for evaluating seasonal  
312 change of copepod community in recent years. In this study, seasonal changes in the  
313 copepod community clearly showed different patterns in each region.

#### 314 4.2. Fram Strait

315 In the eastern Fram Strait, the copepod community changed clearly during the  
316 season. The group H was observed during spring only in eastern Fram Strait and was  
317 characterized by a dominance of *C. finmarchicus*. *C. finmarchicus* is known to be  
318 distributed in the Atlantic sector (e.g., Barents Sea) of the Arctic Ocean, but does not  
319 occur in the Pacific sector (Conover, 1988). However, only a few populations were found  
320 near St. N-4 and St. HG-IV (Conover, 1988; Hirche and Kosobokova, 2007) originally.  
321 In addition, copepodite stage 6 male (C6M) was dominant (maximum 76%) when the  
322 peak of this species was observed (data not shown). In the Barents Sea, C6M in *C.*  
323 *finmarchicus* occur from February to March, but they did not dominate the population  
324 and they disappeared quickly (Tande, 1982). This may show that adult males have a short  
325 life-period. Fram Strait is affected by inflow of the East Greenland Current (EGC) from  
326 the north, the West Spitzbergen Current (WSC) from the south and the Return Atlantic  
327 Current (RAC) from the East, and these currents (WSC and RAC) were most intense  
328 during spring (Beszczynska-Möller et al., 2012; Armitage et al., 2017). From these facts,  
329 C6M of *C. finmarchicus* is thought to be transported from coastal areas of Greenland

330 and/or Svalbard archipelago by WSC and RAC during spring, and they eventually  
331 reached the end of their life-period, and weakened individuals finally sunk and were  
332 collected by the traps. *Paraeuchaeta* spp. and *M. longa* always appeared in the trap  
333 samples because the distribution depth of *P. norvegica* and *P. glacialis* in eastern Fram  
334 Strait is between 0-200 m depth (Laakmann et al., 2009) and *M. longa* mainly occurs at  
335 100-500 m water depth (Conover and Huntley, 1991; Ashjian et al. 2003). *C. hyperboreus*  
336 appeared in spring and autumn. It is known that this species conducts seasonal vertical  
337 migration (Hirche, 1997), therefore, this movement seems to affect their appearance in  
338 the trap samples. In contrast, *C. glacialis* was mainly observed during autumn. This  
339 species usually occurs over continental shelves (Darnis et al., 2008) but few individuals  
340 of the population appear in this study area during sampling (Conover, 1988; Hirche et al.,  
341 1991). Whereas many *C. glacialis* were observed at a 1500 m depth layer in late autumn  
342 in southern Greenland Sea (Hirche, 1991). Thus, this species may have been transported  
343 by currents from coastal areas (e.g. Svalbard archipelago) and must also perform vertical  
344 migration in late autumn. Therefore, movement and distribution depth of respective  
345 species may cause clearly seasonality of copepods community.

346           In the Fram Strait, a strong seasonality of sea ice concentration wasn't observed,  
347 thus Chl. *a* was detected for a long time only interrupted by short sea ice coverage periods.  
348 It is reported that sea ice in the Fram Strait is affected by the Atlantic Water (Beszczynska-  
349 Möller et al., 2012). Although a relationship between environmental factors (SIC and Chl.

350 a) and copepod community structure wasn't analyzed statistically due to lack of  
351 environmental data in this study, obvious relationships were not observed by comparing  
352 with figures except for current. This means that there are several steps in the process until  
353 copepod communities get effected by sea ice melting and freezing. Thus, since only  
354 relationship between current and copepods community structure was thought to be  
355 observed in this study, seasonality as well as variability of current patterns may have  
356 affected the variability of copepod communities in the Fram Strait the most.

#### 357 4.3. Canada Basin

358 Seasonal changes of community structure in St. NAPt and NBC were not  
359 observed, and group C occupied the water column close to the trap during almost during  
360 all periods. Average flux of group C was low and percentages of *M. longa* and *H.*  
361 *norvegicus* were high. Also, share of *Paraeuchaeta* spp. in St. NAPt and St. NBC were  
362 lower than those in the Fram Strait and the MacKenzie Trough. *M. longa* is omnivore, *H.*  
363 *norvegicus* and *Paraeuchaeta* spp. are carnivore (Conover and Huntley, 1991; Nishida  
364 and Ohtsuka, 1996; Dvoretzky and Dvoretzky, 2015). *Paraeuchaeta* spp. have a large  
365 body mass and thus need much more energy for growth compared with *M. longa* and *H.*  
366 *norvegicus* (Ashijian et al., 2003; Kosobokova et al., 2007; Dvoretzky and Dvoretzky,  
367 2015). In this region, seasonality of sea ice concentration was like observed in the  
368 MacKenzie Trough, but surface Chl. *a* concentration was much lower than that of the

369 Fram Strait and the MacKenzie Trough, as primary production is also thought to be low  
370 in the Canada Basin (Arrigo et al., 2008; Pabi et al., 2008). Therefore, *Paraeuchaeta* spp.  
371 could eventually not obtain enough food for completing their life cycle because of too  
372 few small copepods as a prey due to low primary production. This might be the reason  
373 why flux and abundance of *Paraeuchaeta* spp. was low in the copepod community.

374           Short-term seasonal change was observed only at St. NHC in the Canada Basin.  
375 Mooring condition (bottom depth and sediment trap mooring depth) and seasonal change  
376 of copepod communities of St. NHC was like St. MA and St. MG in the MacKenzie  
377 Trough rather than St. NAPt and St. NBC. Moreover, surface zooplankton is transported  
378 by an eddy from the continental shelf to the Canada Basin during summer (Llinás et al.,  
379 2009) and the continental species *C. glacialis* appeared at St. NHC in this study. Lane et  
380 al. (2008) also reported that high abundances of zooplankton around St. NHC was  
381 observed due to horizontal inflow from the continental shelf. Therefore, the observed  
382 complex changes in community structures within the large copepods may be caused by  
383 these transport mechanisms of zooplankton from the continental area. In summary, due  
384 to influence of bottom depth, sediment trap depth and transportation from the continental  
385 area, the copepod community structure of St. NHC exhibits the most complex resembling  
386 short-term changes of the here investigated Arctic regions.

#### 387 4.4. MacKenzie Trough

388           In the MacKenzie Trough, group A occurred frequently, and group B was  
389 observed only during winter. Average flux of group A was higher than those of the other  
390 groups. *Paraeuchaeta* spp., *M. longa* and *C. glacialis* were characteristically dominated  
391 in group A. Because *C. glacialis* is a continental shelf species (Darnis et al., 2008), they  
392 were thought to be observed in St. MA and St. MG where are shallow bottom depth and  
393 locate near continental shelf. According to Darnis et al. (2008), large copepods composed  
394 in order to *C. glacialis*, *C. hyperboreus*, *M. longa* and *P. glacialis* using plankton net  
395 samples in continental shelf of the Beaufort Sea, and *P. glacialis* showed low abundance  
396 and *H. norvegicus* did not occur. In the slope area, however, the large copepods were  
397 abundant in order to *M. longa*, *C. hyperboreus*, *C. glacialis*, *P. glacialis* and *H. norvegicus*,  
398 and the numbers of *P. glacialis* and *H. norvegicus* were low. in contrast, during this study,  
399 *Paraeuchaeta* spp. and *C. glacialis* were dominant in group A and *M. longa* was abundant  
400 in group B, and composition of *Paraeuchaeta* spp. was much greater than that of net  
401 sampling (Darnis et al., 2008). This species is known to be a cruising feeder swimming  
402 actively when they feed on small copepods (Almeda et al., 2017), and this behavior may  
403 be a positive factor to be collected by sediment traps.

404           Moreover, we compared samples among St. MA (shallow, 72 m), St. MG  
405 (shallow, 125 m) and St. MA (deep, 172 m) to analyze effect of trap depth because St.  
406 MA and St. MG deployed near and mooring period were same. Group A occurred when  
407 the sediment trap depth was shallower, and the other groups (e.g., group G and group F)

408 were observed as the sediment trap depth was deeper. Also, *Paraeuchaeta* spp. and *C.*  
409 *glacialis* showed higher abundances at shallow depth and that of *M. longa* and *C.*  
410 *hyperboreus* increased with deeper sediment trap depth. These facts mean that vertical  
411 distribution of the various species overlapped at deep sediment trap depth. Thus,  
412 community structure in shallow depth of the MacKenzie Trough showed no seasonal  
413 changes in the dominance of *Paraeuchaeta* spp. and *C. glacialis* because all the other  
414 large species (*C. hyperboreus* and *M. longa*) didn't overlap in the shallower layer. Flux  
415 of *Paraeuchaeta* spp. and *C. glacialis* decreased with increasing depth and distribution  
416 depth of the other species overlapped. Hence complex seasonal changes of copepod  
417 community structures were observed at deeper layers.

418 In the MacKenzie Trough, sea ice concentration changed like in the Canada  
419 Basin and surface Chl. *a* was higher than the other regions. Neither remarkable (St. MA  
420 shallow) nor short-term (St. MG and St. MA deep) seasonality of community structure  
421 was observed in this region. Especially, high-flux group A was observed throughout the  
422 year, which wasn't observed in the other regions. This may be induced by small sediment  
423 trap open area (0.125 m<sup>2</sup>).

424 Since only one-year observation was performed in the MacKenzie Trough, we  
425 cannot consider the observed species compositions found in the trap samples as the  
426 usually occurring structure. Based on same the sampling program in 2009-2010,  
427 maximum flux of *Paraeuchaeta* spp. was 971 ind. m<sup>-2</sup> day<sup>-1</sup> at St. MA (shallow) and 701

428 ind.  $\text{m}^{-2} \text{day}^{-1}$  St. MG (shallow), and *Paraeuchaeta* spp. dominated (data not shown)  
429 similar to results of this study. In addition, Dezutter et al. (2019) reported that high flux  
430 of *C. glacialis* was observed in sediment trap samples at the MacKenzie Trough, although  
431 interannual variability was observed. Thus, the tendency we found is thought to be a  
432 common feature of sediment trap samples over the MacKenzie Trough eventually caused  
433 by high concentrations of surface chl. *a* across the MacKenzie Trough compared to all  
434 other regions investigated in this study.

#### 435 *4.5. Regional comparison*

436           Seasonal changes of copepods community structure obtained with sediment trap  
437 samples showed large variations among the investigated regions, and in summary, three  
438 patterns of seasonal changes were observed in this study: clear seasonal changes (eastern  
439 Fram Strait), no seasonal change (Canada Basin) and changes within short periods  
440 (MacKenzie Trough). The following three points could be mentioned as factor of these  
441 differences. First point is the influence of the sediment trap depth. With or without  
442 seasonal change we found differences only due to the chosen sediment trap depth in the  
443 MacKenzie Trough samples, and group A which showed a high flux rate, was observed  
444 mainly at shallow depths. Therefore, effects of sediment trap depth should not be ignored  
445 for evaluating zooplankton community by sediment traps. Second point is horizontal  
446 transportation of copepods by currents. Ocean-specific community (e.g., group H)

447 characterized by *C. finmarchicus* was observed only in the Fram Strait due to the inflow  
448 of the Atlantic water. Also, transportation from shelf areas led to specific short-term  
449 changes in community structures at St. NHC even in Canada Basin where usually little  
450 seasonality is reported. Third point is the hydrographic environment and related to this as  
451 biological factor, especially primary production here expressed as surface Chl. *a*  
452 concentration. The latter was quite high over the MacKenzie Trough, but low in the  
453 eastern Fram Strait and the Canada Basin (Arrigo et al., 2008; Pabi et al., 2008; in this  
454 study), and copepod fluxes showed the same patterns. In addition, dominant species of  
455 group A, which had the highest flux of all samples examined, were observed in the eastern  
456 Fram Strait and Canada Basin, but they were especially abundant in group A. If this fact  
457 is true, not only flux but also dominant species of copepods would be driven rather by the  
458 feeding environment (primary production) than by anything else between regions in the  
459 Arctic Ocean. However, in this study, relationship between seasonal change of sea ice  
460 concentration and copepods community structure was complex. In the Fram Strait, sea  
461 ice concentration showed diffuse seasonal changes, but the copepods community  
462 structure exhibited a clear seasonality. In the Canada Basin, seasonal change of sea ice  
463 concentration was evident and copepods community structure didn't show any variation.  
464 In the MacKenzie Trough, remarkable seasonal changes of sea ice concentration and  
465 short-term seasonal change of copepods communities were observed. Thus, seasonality  
466 of sea ice concentration may not affect directly large copepods community structures in

467 all region.

468           Seasonal changes of copepod community structures within Arctic Ocean was  
469 shown to be quite different between the three regions in this study. It was additionally  
470 discussed that these differences were influenced by several environmental factors (sea ice  
471 concentration, current patterns, endemic species occurrence and the amount of primary  
472 production). These discussions couldn't be obtained when only using plankton net sample  
473 collected during the short Arctic summer. However, also variations of mooring situations  
474 (e.g. mooring periods, depth and site) between regions seemed to affect the seasonal  
475 change of large copepods community structure in this study. Therefore, for more robust  
476 comparison, exhaustive observation webs of sediment traps and comparison of seasonal  
477 changes within same deployment depths and same sampling periods are required for  
478 different regions in the Arctic Ocean.

#### 479 **Acknowledgements**

480           We would like to thank captain and crew of Japan agency for Marine-Earth  
481 Science and Technology RV *Mirai*, Alfred Wegener Institute Helmholtz Centre for Polar  
482 and Marine Research (AWI) RV *Polarstern* and Canadian Coast Guard RV *Amundsen*  
483 and IB *S.W. Laurier*. We also thank Nadine Knüppel at the AWI for picking copepods in  
484 Fram Strait samples. We also express our sincere thanks to support Program for Overseas  
485 Visits by Young Researchers of Arctic Challenge for Sustainability (ArCS). Part of this

486 study was supported by a Grant-in-Aid for Scientific Research 19H03037 (B), 18K14506  
487 (Early Career Scientists) and 17H01483 (A) to KT, 22221003 (S), 15H05712 (S) to NH,  
488 15H01736 to JO from the Japan Society for the Promotion of Science (JSPS).

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634 **Figure/table captions**

635 **Fig. 1.** Location of the 3 mooring sites: Fram Strait, Canada Basin, MacKenzie Trough.

636 Fram Strait was sampled at two stations (St. N-4 and St. HG-IV) from 15 July  
637 2010 to 15 June 2014. Canada Basin was sampled at three stations (St. NAPt, St.  
638 NHC and St. NBC) from 04 October 2010 to 10 September 2016. MacKenzie  
639 Trough was sampled two stations (St. MG and St. MA) from 14 September 2011  
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641 Current, RAC; East Greenland Current; EGC.

642 **Fig. 2.** Seasonal changes in sea ice concentration and surface Chl. *a* at each mooring  
643 station. Open and solid bars indicate the period of the midnight sun and polar  
644 night, respectively. (Pay attention to the different scales on y-axis).

645 **Fig. 3.** Seasonal changes on copepods abundance and community structure in the Arctic  
646 Ocean. (Pay attention to the different scales on y-axis).

647 **Fig. 4.** Dendrogram showing the Bray-Curtis similarity results based on zooplankton  
648 flux (a). Ten groups (A-J) were identified at 74% similarity. Numbers in  
649 parentheses indicate the number of stations included in each group. NA: not  
650 available. The mean flux and species composition of each group (b).

651 **Fig. 5.** Seasonal changes in occurrence of copepod groups identified by cluster analysis  
652 on flux (cf. Fig. 4) at each station in the Arctic Ocean. Copepods groups were  
653 identified 10 groups (A-J) by Bray-Curtis similarity (cf. Fig. 4). Cross: no data,

654 slash: not available, blank: no sampling.

655 **Table 1.** Information of trap deployments and collected samples by means of sediment  
656 traps at each investigated station in the Arctic Ocean.

657 **Table 2.** Size categories of the prosome length for identifying the *Calanus* species in the  
658 Fram Strait (cf. Hirche et al., 1994; Kosobokova and Hirche, 2016).

659 **Table 3.** Mean flux and contribution in percent for species in clustering groups (cf. Fig.  
660 4a) in the Arctic Ocean. The dominant species were shown based on the  
661 contribution percent according to SIMPER.

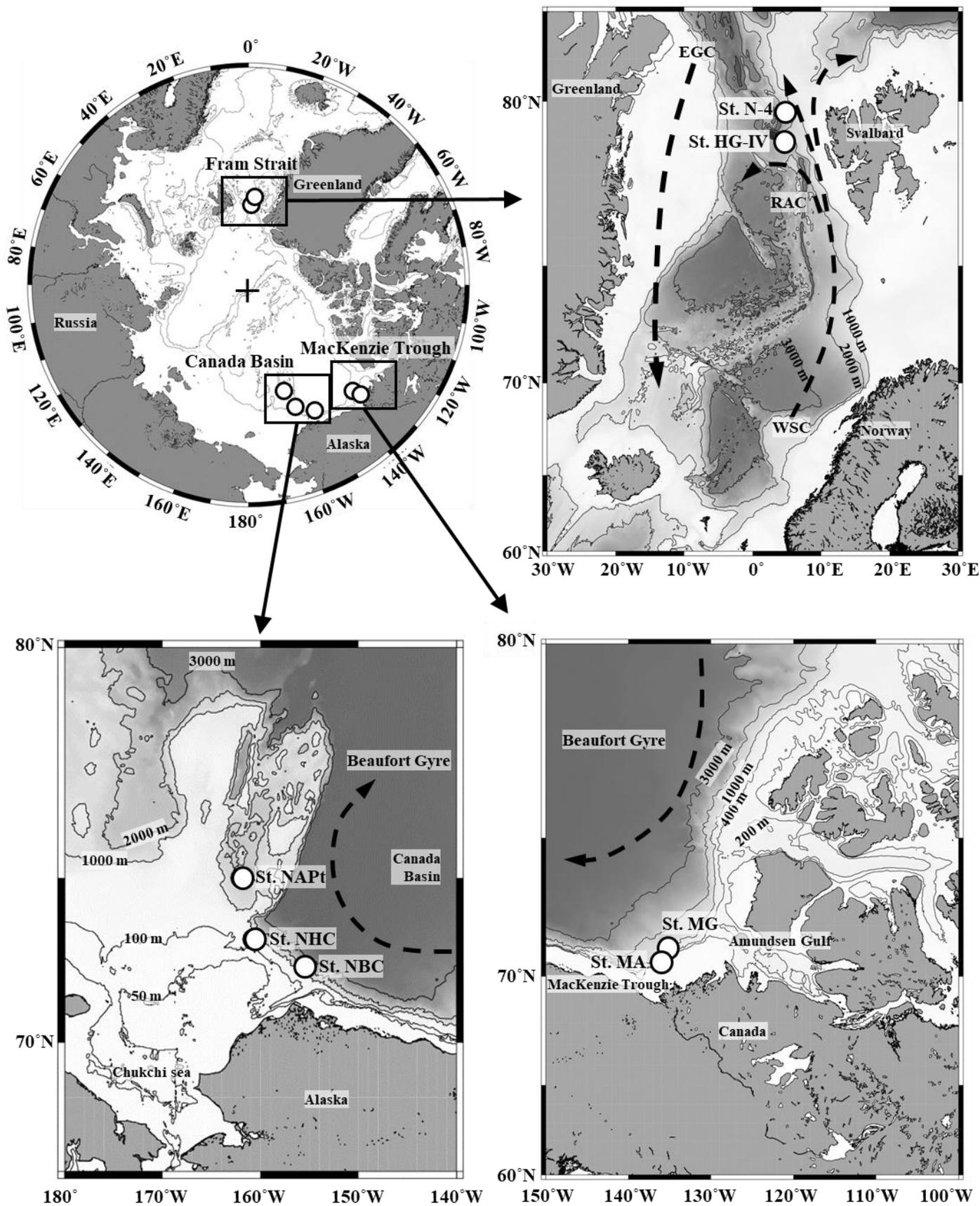


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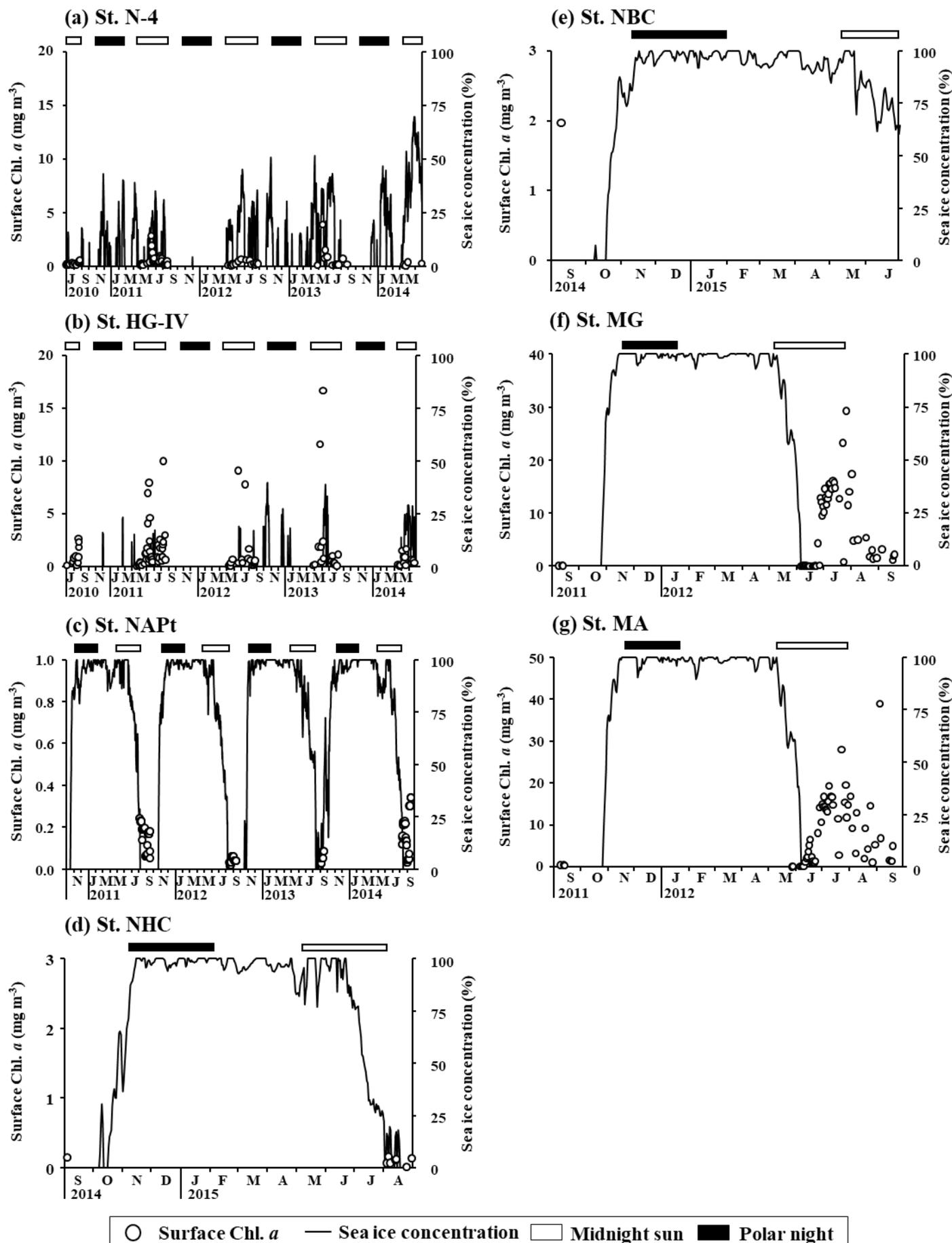


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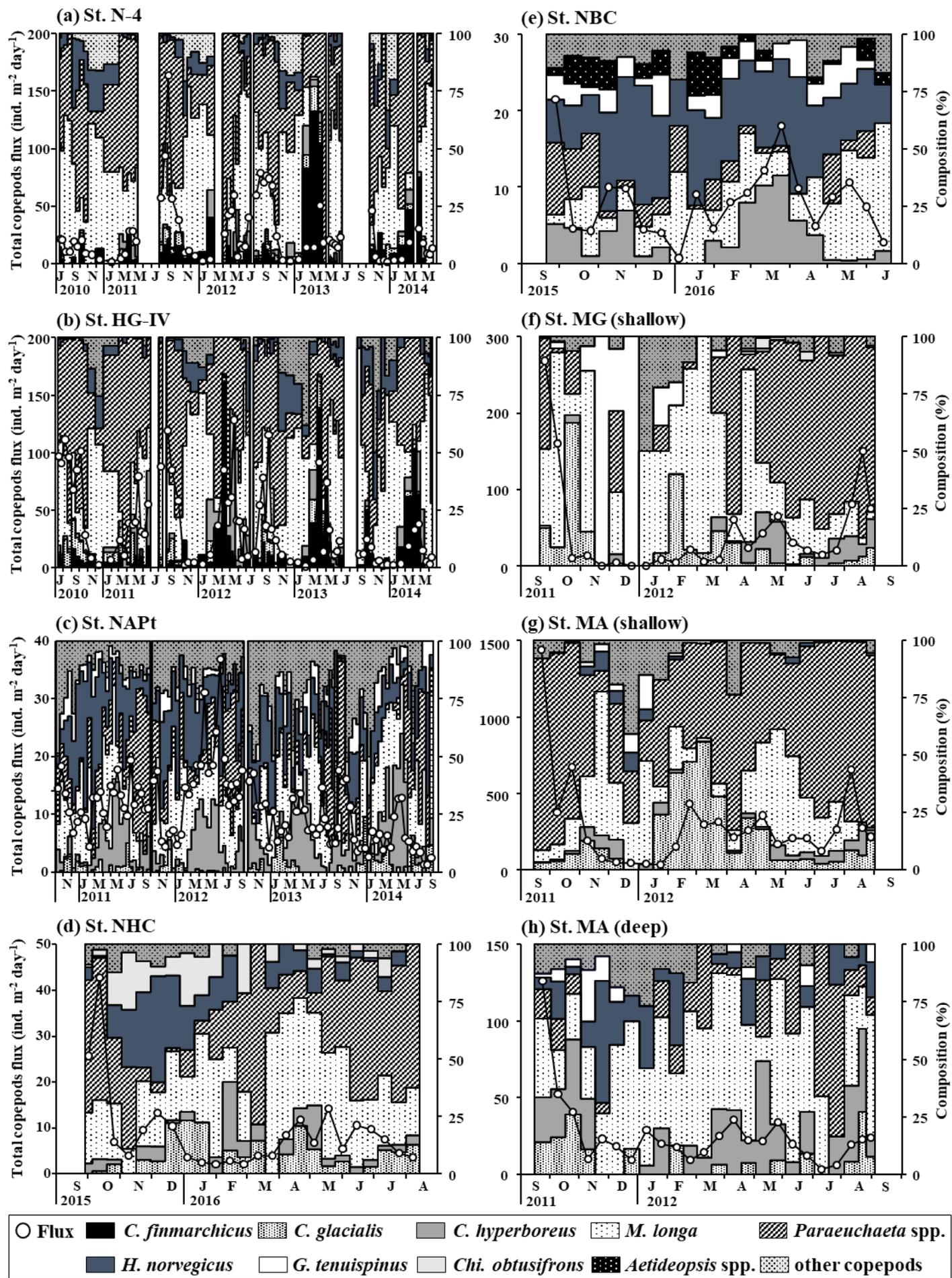


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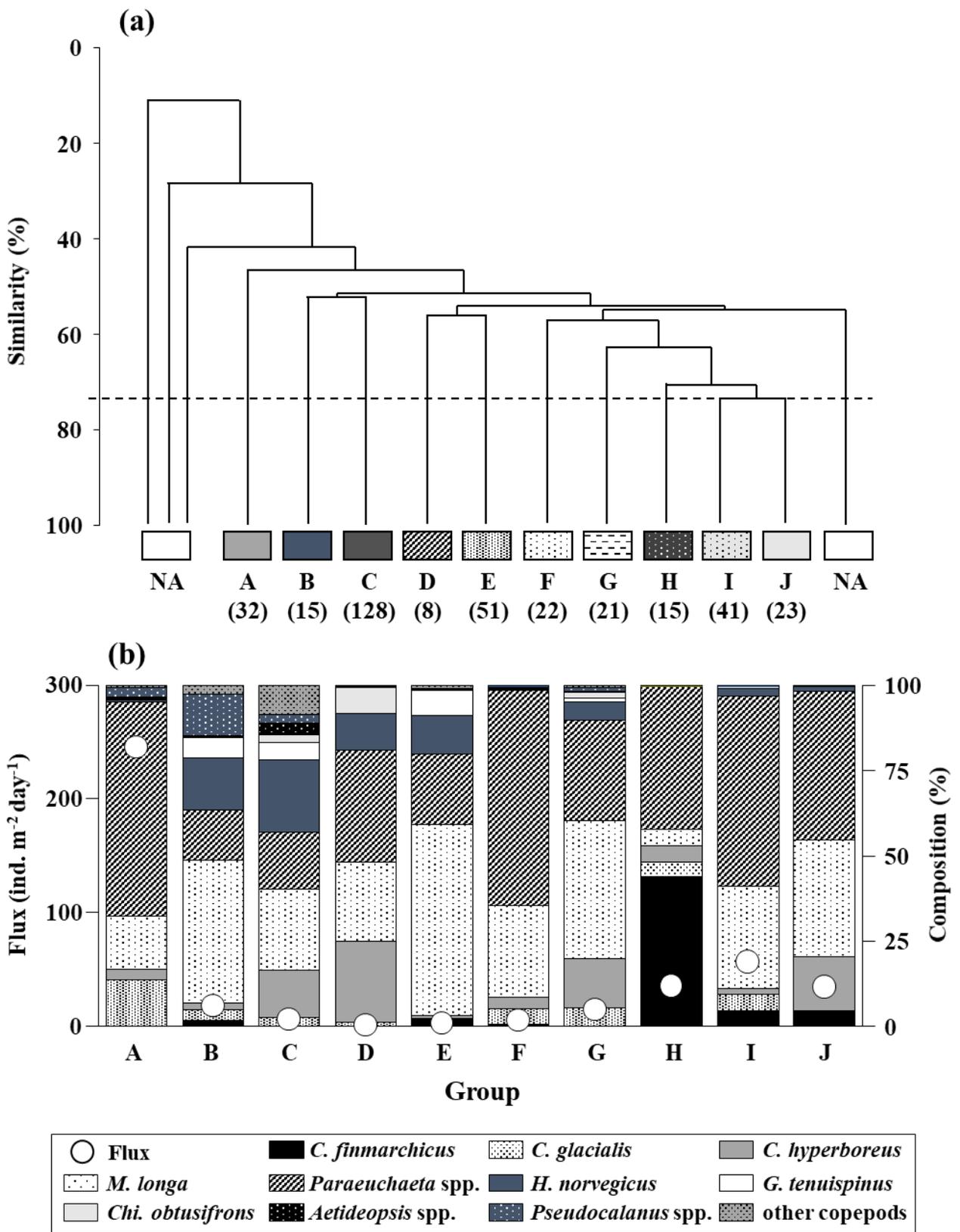


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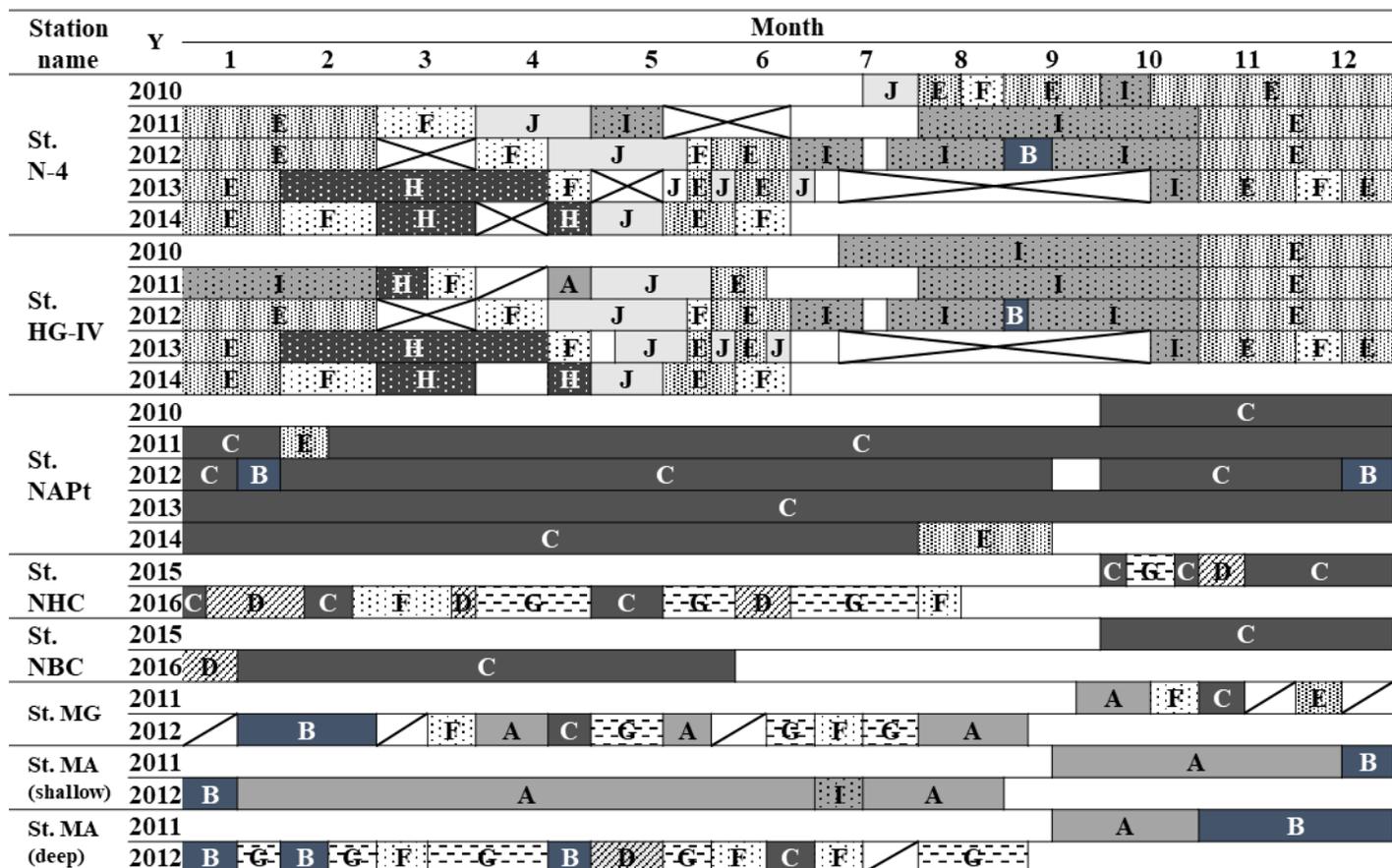


Fig. 5. Seasonal changes in occurrence of copepod groups identified by cluster analysis on flux (cf. Fig. 4) at each station in the Arctic Ocean. Copepods groups were identified 10 groups (A-J) by Bray-Curtis similarity (cf. Fig. 4). Cross: no data, slash: not available, blank: no sampling.

Table 1. Information of trap deployments and collected samples by means of sediment traps at each investigated station in the Arctic Ocean.

Mooring point	Mooring period	Lat.	Long.	Water depth (m)	Trap depth (m)	Open area (m <sup>2</sup> )	Collection days	No. of cups
Fram Strait (St. N-4)	1st year (15.07.2010-30.06.2011)	79.74N	4.50E	2677	190	0.5	5-59	20
	2nd year (01.08.2011-15.07.2012)	79.74N	4.51E	2667	200	0.5	10-32	20
	3rd year (27.07.2012-30.06.2013)	79.74N	4.51E	2667	205	0.5	10-31	20
	4th year (05.07.2013-15.06.2014)	79.74N	4.50E	2675	205	0.5	7-31	20
Fram Strait (St. HG-IV)	1st year (10.07.2010-30.06.2011)	79.00N	4.33E	2604	200	0.5	10-59	20
	2nd year (01.08.2011-15.07.2012)	79.01N	4.33E	2605	200	0.5	10-32	20
	3rd year (29.07.2012-30.06.2013)	79.01N	4.51E	2642	205	0.5	10-31	20
	4th year (10.07.2013-15.06.2014)	79.06N	4.03E	2577	205	0.5	7-31	20
Northwind Abyssal Plain (St. NAPt)	1st year (04.10.2010-28.09.2011)	75.01N	162.17W	1973	186	0.5	13-15	26
	2nd year (04.10.2011-18.09.2012)	75.11N	175.00W	1975	260	0.5	10-15	26
	3rd year (04.10.2012-18.09.2013)	75.00N	162.00W	1975	222	0.5	10-15	26
	4th year (10.09.2013-10.09.2014)	74.33N	161.58W	1715	189	0.5	14-15	26
North of Hanna Canyon (St. NHC)	1st year (28.09.2015-10.09.2016)	73.30N	199.22W	426	170	0.5	7-14	26
North of Barrow Canyon (St. NBC)	1st year (21.09.2015-09.09.2016)	72.47N	204.59W	2000	250	0.5	12-14	26
MacKenzie Trough off the coast (St. MG)	1st year (20.09.2011-02.09.2012)	71.00N	135.29W	705	125	0.5	8-16	24
MacKenzie Trough off the coast (St. MA) shallow	1st year (14.09.2011-02.09.2012)	70.45N	136.00W	659	72	0.125	8-17	24
MacKenzie Trough off the coast (St. MA) deep	1st year (14.09.2011-02.09.2012)	70.45N	136.00W	659	172	0.125	8-17	24

Table 2. Size categories of the prosome length for identifying the *Calanus* species in the Fram Strait (cf. Hirche et al., 1994; Kosobokova and Hirche, 2016).

Species	Females	C5	C4	C3
<i>C. finmarchicus</i>	<3.1 mm	<2.9 mm	<2.2 mm	<1.7 mm
<i>C. glacialis</i>	>3.1 mm	>2.9 mm	>2.2 mm	>1.7 mm
<i>C. hyperboreus</i>			>3.0 mm	>2.0 mm

Table 3. Mean flux and contribution in percent for species in clustering groups (cf. Fig. 4a) in the Arctic Ocean. The dominant species were shown based on the contribution percent according to SIMPER.

Group	Species	Mean flux (ind. m <sup>-2</sup> day <sup>-1</sup> )	Contribution (%)	Group	Species	Mean flux (ind. m <sup>-2</sup> day <sup>-1</sup> )	Contribution (%)
A	<i>Paraeuchaeta</i> spp.	156.69	58.52	F	<i>Paraeuchaeta</i> spp.	6.28	70.13
	<i>M. longa</i>	38.82	19.77		<i>M. longa</i>	2.70	24.68
	<i>C. glacialis</i>	33.88	13.21		<i>C. hyperboreus</i>	0.33	3.40
	<i>C. hyperboreus</i>	7.92	5.57		<i>C. glacialis</i>	0.46	1.35
	<i>Pseudocalanus</i> spp.	7.33	1.41		<i>C. finmarchicus</i>	0.05	0.29
B	<i>M. longa</i>	9.49	52.73	G	<i>M. longa</i>	7.81	50.66
	<i>H. norvegicus</i>	3.47	20.46		<i>Paraeuchaeta</i> spp.	5.66	28.13
	<i>Pseudocalanus</i> spp.	2.78	11.97		<i>C. hyperboreus</i>	2.75	9.55
	<i>G. tenuispinus</i>	1.36	4.96		<i>H. norvegicus</i>	1.01	5.98
	<i>C. glacialis</i>	0.67	4.39		<i>C. glacialis</i>	1.06	4.11
C	<i>M. longa</i>	2.60	30.38	H	<i>Paraeuchaeta</i> spp.	16.73	52.20
	<i>H. norvegicus</i>	2.32	26.75		<i>C. finmarchicus</i>	17.41	33.67
	<i>Paraeuchaeta</i> spp.	1.82	11.89		<i>M. longa</i>	1.94	6.06
	<i>C. hyperboreus</i>	1.52	11.80		<i>C. hyperboreus</i>	1.82	4.67
	<i>G. tenuispinus</i>	0.57	6.42		<i>C. glacialis</i>	1.78	3.34
D	<i>M. longa</i>	1.36	40.84	I	<i>Paraeuchaeta</i> spp.	33.92	55.52
	<i>Paraeuchaeta</i> spp.	1.93	27.49		<i>M. longa</i>	18.29	29.94
	<i>H. norvegicus</i>	0.63	18.80		<i>C. glacialis</i>	3.03	4.96
	<i>Chi. obtusifrons</i>	0.45	12.35		<i>C. finmarchicus</i>	2.76	4.52
	<i>C. hyperboreus</i>	1.40	0.52		<i>H. norvegicus</i>	1.50	2.46
E	<i>M. longa</i>	4.08	60.09	J	<i>Paraeuchaeta</i> spp.	17.10	43.52
	<i>Paraeuchaeta</i> spp.	1.50	16.98		<i>M. longa</i>	13.46	34.25
	<i>H. norvegicus</i>	0.84	11.43		<i>C. hyperboreus</i>	6.26	15.94
	<i>G. tenuispinus</i>	0.55	9.15		<i>C. finmarchicus</i>	1.78	4.52
	<i>C. finmarchicus</i>	0.14	1.55		<i>H. norvegicus</i>	0.60	1.52